National Research Council Canada
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Division of Energy
Division de l'énergie

Solar Energy Program
Programme d'énergie solaire

Residential Passive Solar Design: A Guide to the Technology

Timothy Mayo

July 1986

Canada

NRCC No. 26252

86-06451/

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This project was supported by the Federal Panel of Energy R/D (PERD).

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by Timothy Mayo

National Research Council of Canada
Ottawa
July 1986

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PREFACE

This Primer is for everybody interested in passive solar and low energy houses. It provides an overview of current Canadian technology, explains the issues, and offers advice based on recent research. It lists references for more specific information.

Most of the information here is based on work conducted in the private sector and funded by the Solar Energy Program at the National Research Council up to March 1986. Federal government support for research and development in solar energy now rests with Energy, Mines and Resources, where the Solar Energy Development Program is responsible for research into passive solar energy.

Progress in passive solar technologies has been substantial. Further research in the most promising areas is expected to lead to a new generation of passive solar products offering a significant impact on conventional energy consumption in Canadian houses.

PRÉFACE

Ce livre élémentaire est destiné à tous ceux qui s'intéressent aux habitations à chauffage solaire passif et à haut rendement énergétique. Il donne un aperçu général de la technologie canadienne courante, explique les problèmes et offre des conseils basés sur les recherches récentes. Il donne aussi une liste de référence pour obtenir des informations plus précises.

Une bonne partie de l'information fournie est fondée sur les travaux de recherche effectués au sein du secteur privé et financés par le Programme d'énergie solaire du Conseil national de recherches jusqu'en mars 1986. L'aide fournie par le gouvernement fédéral à la recherche et au développement en matière d'énergie solaire provient maintenant d'Énergie, Mines et Ressources, dont le Programme de développement de l'énergie solaire est responsable de la recherche sur l'énergie solaire passive.

Les progrès réalisés jusqu'à présent au niveau des techniques solaires passives sont considérables. On s'attend à ce que la poursuite des recherches dans les secteurs les plus prometteurs conduise à une nouvelle génération de produits solaires passifs influant de façon significative sur la consommation classique d'énergie dans les habitations canadiennes.

1 INTRODUCTION TO PASSIVE SOLAR

Passive solar houses are designed to offer aesthetic improvement in indoor quality by providing bright, open spaces where the winter sun can shine in through the windows. Landscaping and shading keep out the summer sun while during the heating season, solar gains provide a considerable portion of the energy requirements, particularly if the house is energy efficient.

In technical terms, these houses collect solar radiation through their windows and store the heat gains within the building for use later when the sun is no longer shining. Because the occupants are living inside a solar collector, good design is essential.

The three key components any passive house are the windows, thermal storage, and a heat distribution system. If the window area is too large or the thermal storage capacity too small or the distribution system too slow, the building will overheat during sunny periods year-round. If the window area is too large, the house will overcool during the winter when the sun isn't shining, thus requiring purchased energy for auxiliary heating.

Depending on their strategy for optimizing solar input while reducing overheating and cooling, passive solar systems are divided into three basic types — direct gain, indirect gain, and isolated gain.

Direct gain systems are the simplest. Any house with south-facing windows is a direct gain system. Solar energy shines through the windows and the direct heat gains are immediately available to the adjacent spaces. Thermal storage is supplied by the building materials. While some houses rely on natural convection to circulate the solar gains, performance improves if a circulating fan, usually the furnace fan, distributes the heated air throughout the house.

Indirect gain systems feature a heavy mass wall just inside the windows to absorb the solar gains and then radiate them inward during the night. These mass-wall systems are more popular in warmer climates where shade from the hot sun is appreciated and the thermal mass soothes out the strong temperature variations.

Isolated gain systems feature a solarium or sunroom where the solar-heated space is isolated from the living space. Isolated gain systems try to avoid overheating the house by placing the problem somewhere else — in the sunspace. Both indirect-gain and isolated-gain strategies are attempts to control solar gains and reduce any overheating.

Research into these three systems has produced a clear conclusion that in Canada direct-gain systems make the most sense. Cost-effective passive solar design for Canadian houses calls for emphasizing south-facing windows without adding more window area than is aesthetically desirable or required by building regulations.

With existing technology, the optimum south-facing window area is typically 8-10% of the building's floor area. With this amount of window area, conventional building materials (such as gypsum wallboard, hardwood floors, and ceramic tile) will provide adequate thermal storage, while overheating and overcooling will

be avoided. Larger south window areas can be used, but costs are higher for the extra windows, extra mass and extra distribution required, and unless great care is taken in the design stage, overheating, glare, overcooling and increased purchased energy consumption can result.

The energy performance of any passive solar/low energy house is dependent on how the occupants use it. Studies carried out on similar families in identical houses have shown energy consumption rates can vary by a factor of two. Some responsibility is required on the part of the user to keep energy consumption low and the solar contribution high.

2 LOW-ENERGY BUILDING

The aim of passive solar design and low-energy building is the same: to produce a comfortable house and to reduce purchased energy consumption in a cost-effective manner. Both approaches achieve this goal by integrating features into the building construction itself.

Conservation focusses on simple building trade practices, such as increased insulation levels, sealed air/vapour barriers, and heat-recovery ventilation to produce savings. Passive solar optimizes solar contributions to reduce auxiliary heating costs.

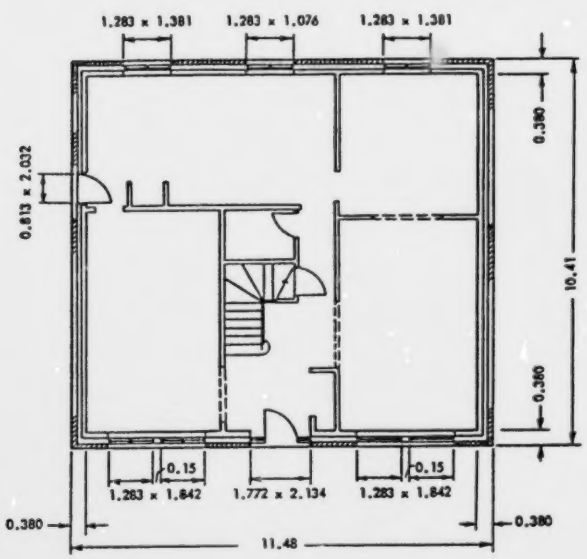
TERMS AND CONCEPTS

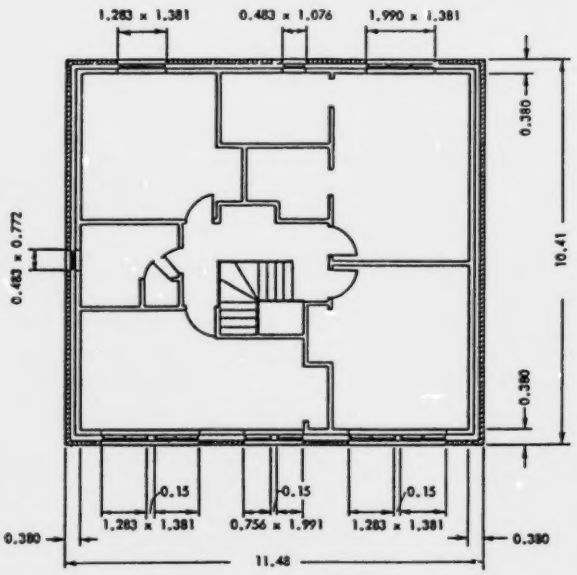
Reference House

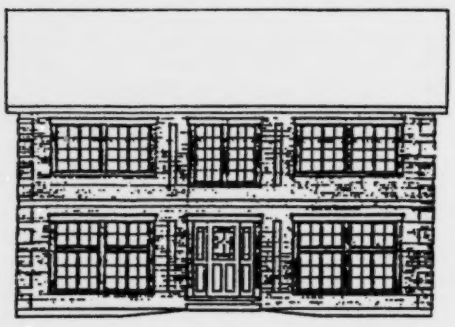
This section contains information on a typical Reference House to provide a benchmark for evaluating different thermal performance strategies. It provides information on insulation levels and heating energy requirements and discusses R-2000 performance standards, which currently represent the state-of-the-art in low-energy houses in Canada.

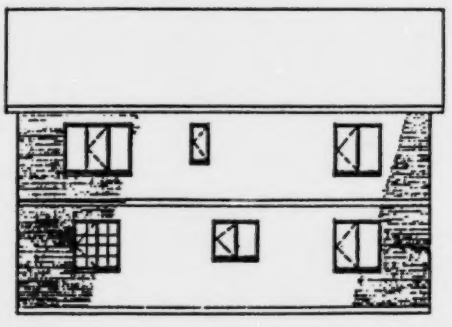
The Reference House used for all the calculations is assumed to be a 200 m^2 two-storey house located in Ottawa. A large house was chosen because it is typical of a significant component of the future up-scale housing market, particularly as "baby boomers" move up to their second house. The Ottawa site was chosen because it provides climatic conditions and heating loads approximately midway between those on the Prairies and on both coasts. Costs given here are those estimated for the Reference House and are intended to provide an approximate figure for most typical houses.

Plans and Elevations for Reference House









Measures for Energy Conservation

Specific insulation requirements are not contained in the National Building Code, although both Ontario and Quebec have included mandatory levels in their provincial building codes. Nationally, insulation levels are spelled out in a non-mandatory companion to the National Building Code entitled **Measures for Energy Conservation in New Buildings**. In **Measures**, minimum insulation levels are specified by building component, depending on the number of heating degree-days where the building is located.

For the Reference House in Ottawa, with 4763 heating degree days Celsius, the insulation requirements in **Measures** for ceilings are RSI 5.6 (R-30), walls RSI 3.6 (R-20), and basement walls RSI 2.2 (R-12).

Insulation Requirements from Measures for Energy Conservation, 1983

MINIMUM THERMAL RESISTANCE, RSI[1]					
Building Assembly	Maximum Number of *Degree Days*				
	3 000	3 500	5 000	6 500	8 000 and over
Wall assemblies above ground level (other than foundation walls) separating *heated space* from *unheated space* or the outside air	2.8 R-16	3.0 R-17	3.6 R-20.5	4.1 R-23.5	4.5 R-25.5
Foundation wall assemblies separating *heated space* from *unheated space*, outside air or adjacent earth	2.2 R-12.5	2.2 R-12.5	2.2 R-12.5	2.2 R-12.5	2.2 R-12.5
Roof or ceiling assemblies separating *heated space* from *unheated space* or the exterior	4.4 R-25	4.7 R-27	5.6 R-32	6.4 R-36.5	7.1 R-40.5
Floor assemblies separating *heated space* from *unheated space* or the exterior	4.7 R-27	4.7 R-27	4.7 R-27	4.7 R-27	4.7 R-27
Perimeters of slab-on-ground floors that are less than 600 mm below adjacent ground level (insulation only)					
(a) slabs where heating ducts, pipes or resistance wiring are embedded in or beneath the slabs	0.9 R-5	1.3 R-7.5	1.7 R-10	2.1 R-12	2.5 R-14
(b) slabs other than those described in (a)	0.4 R-2.5	0.8 R-4.5	1.3 R-7.5	1.7 R-10	2.1 R-12
Column 1	2	3	4	5	6

Heating Loads

Heating loads are measured in kilojoules, the metric equivalent of the British Thermal Unit, or Btu. The two are almost equal: 1 Btu equals 1.055 kJ. To keep the numbers small, heating loads are usually given in Megajoules (one thousand kilojoules) or even Gigajoules (one million kilojoules or one thousand megajoules). To provide a sense of scale for these units, a typical Canadian family requires 18 GJ annually, or about $230, to heat its domestic hot water.

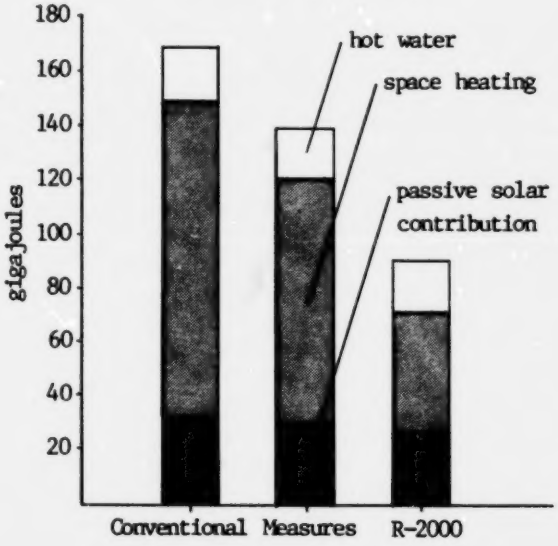
METRIC EQUIVALENTS

* Burning one litre of fuel oil generates 38.7 megajoules
* Burning 100 m^3 of natural gas generates 1170 MJ
* One kilowatt hour of electricity generates 3.6 MJ of heat
* One GJ is the energy equivalent of 30 litres of gasoline

Reference House Energy Requirements

The 200 m^2 Reference House, if built to traditional insulation levels would have RSI 2.1 (R-12) walls, RSI 3.4 (R-20) ceil gs, and RSI 1.4 (R-8) basement walls, but only to 600 mm (2 ft.) below grade. Windows would be double-glazed and airtightness could vary greatly but could be as low as 0.5-1.0 ACH if constructed by a careful builder. Under these conditions its annual energy load would be about 168 Gigajoules -- 150 GJ for space heating and 18 GJ for hot water. Passive solar gains would provide about 32 GJ toward the space heating load.

Reference House Energy Loads



When insulated to Measures standards--increased wall, ceiling and basement wall insulation but no basement floor insulation, double-glazed windows and a natural 0.4 ACH -- the Reference House has a total energy load reduced to 140 GJ. The space heating load is 122 GJ, less a passive contribution of 31 GJ, for a purchased energy requirement of 91 GJ.

When upgraded to R-2000 standards, the space heating load drops to 72 GJ, less a 27 GJ passive contribution, for a net purchased requirement of 45 GJ.

Hot water heating energy requirements are 18 GJ, the same for all versions.

R-2000 Program

R-2000 houses are built under the Super-Energy-Efficient Housing program established by the federal government as a joint government/private-sector venture that sets energy performance standards for new houses. R-2000 houses feature high levels of insulation, tight construction, air-to-air heat recovery ventilation systems, and down-sized heating systems. Typically, R-2000 houses provide 40-50% energy savings over conventional houses built to **Measures** standards.

The initial R-2000 demonstration homes cost an average of $6300 more than conventional houses, but are cheaper to finance and operate due to savings in purchased energy costs. The program is encouraging the construction of 20,000 energy efficient houses over the next five years. To be eligible for construction as an R-2000 house, a design is modelled on a computer program (HOT-2000, an updated version of

HOTCAN) and must meet a performance standard based on a calculated annual energy consumption target for space and water heating.

The R-2000 performance target initially could be met by incorporating airtight construction, high insulation levels and an air-to-air heat exchanger. Recent changes to the requirements now permit trading-off between mechanical system efficiency and building envelope design with an improved mechanical system. This approach can allow increased solar gains to contribute to the hot water heating energy load.

To meet the R-2000 standard, the Reference House needs to have its annual purchased space heating energy consumption reduced to less than 45 GJ. One method of achieving this reduced load would require upgrading the ceiling insulation to RSI 9.0 (R-50), the walls to RSI 5.6 (R-32), the basement walls to RSI 3.5 (R-20), and the basement floor to RSI 1.8 (R-10), plus triple-glazed windows on the north, east and west sides. A tight air/vapour barrier and an air-to-air heat exchanger would also be required.

REFERENCE HOUSE ANNUAL HEATING ENERGY LOADS AND COSTS

(based on energy at 4.6¢ per kWh or $12.75 per GJ)

	Space Heating		Hot Water	
	Load	Cost	Load	Cost
Conventional construction	118 GJ	$1,508	18 GJ	$ 230
"Measures" insulation	91 GJ	$1,163	18 GJ	$ 230
R-2000 standard	45 GJ	$ 573	18 GJ	$ 230

The cost of upgrading the Reference House to the R-2000 standard is estimated at $6415, producing a simple payback of 10.8 years assuming energy costs at $12.75 per GJ (or 4.6¢ per kWh).

CURRENT TECHNOLOGY

Canada has been a pioneer in passive solar and low-energy building technology, largely as a result of the oil crisis of the mid-1970's.

Saskatchewan Conservation House

The Saskatchewan Conservation House, built in 1977, kicked off the Canadian low-energy building movement. Intended as a public demonstration of new construction strategies for cold northern climates, the Saskatchewan Conservation House featured superinsulation and airtight construction, plus a prototype air-to-air heat exchanger for indoor ventilation. Seven of its nine windows, shaded by overhangs in summer and fitted with movable insulation against winter losses, were south-facing for solar gain.

Conservation House was 85 percent more energy efficient than conventional houses of the day, with a total annual heat loss of only 19.5 GJ. Its heating costs in the 1970's were less that $100 a year.

Following that technical success, a 14-unit market housing project in Saskatoon convinced the building industry that low-energy building technology was transferable to the mass housing market. By 1982, 52 percent of housing starts in Saskatchewan were being built to low-energy standards. Impressed with the results of these demonstrations, the Federal government initiated the R-2000 program.

THREE ESSENTIAL FEATURES OF CURRENT TECHNOLOGY

* airtight construction
* superinsulation
* air-to-air heat exchangers for ventilation

Airtight Construction

A tight air barrier is key to current low-energy houses. Installed so that it completely seals the building envelope -- foundations, walls, and ceilings -- the air barrier's job is to stop air infiltration. The problem with airtight construction is the difficulty of building the house tight during construction in the first place and then ensuring that it will remain tight for the life expectancy of the building.

Fan Door for Testing Airtightness

Airtightness requires a careful, well-trained crew on the construction site and an air-pressure test to assure quality control. The increased cost, currently estimated at over $600 to bring the Reference House up to R-2000 requirements, is largely due to difficult quality control and time-consuming sealing, rather than to the cost of the materials themselves.

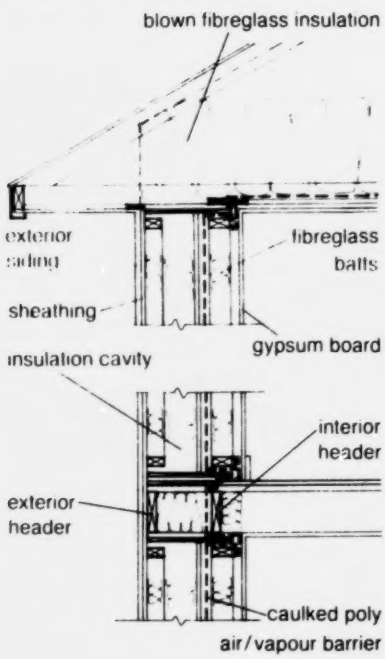
Polyethylene sheet, preferably 6 mil thick for strength and puncture resistance, is usually used, often placed between layers of insulation to protect it from damage during construction and caulked at all overlaps to ensure a tight seal.

Many builders also wrap the outside of their houses with special films which are vapour permeable but which act as an air barrier. An alternative technique avoids the use of polyethylene altogether by relying on specially painted wallboard to act as the vapour barrier in conjunction with carefully installed foam gaskets at all the joints to function as the air barrier.

Superinsulation

Superinsulation, the second feature of current technology, is both labour and material intensive. Superinsulation involves expanding the framing of exterior walls to make room for extra layers of insulation to minimize energy losses to the cold outside air. In milder Canadian climates, 38 mm x 140 mm (2 x 6 in.) framing is typical, with strapping on the inside or the outside to allow for the extra layer of insulation.

Superinsulated Double-Stud Wall



In colder climates, walls are often double-framed to allow for increased insulation within the wall. Typical superinsulation levels are RSI 10.5 (R-60) in attics, RSI 7.0 (R-40) in walls, and RSI 3.5 (R-20) in basement walls. Basement floors are also insulated against heat losses to the ground, at least to RSI 1 (R-6) and sometimes more.

Field experience over the past ten years has led to the general understanding that the law of diminishing returns applies to superinsulation techniques. Thus the higher costs associated with both the materials and their installation are found to become less cost-effective as increasing thicknesses of insulation are added.

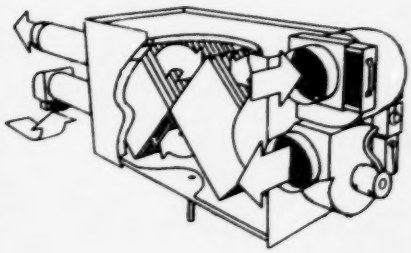
Thicker double-stud wall construction and superinsulation for the Reference House to allow it to meet the R-2000 performance standard would cost an estimated $3000-4000.

Mechanical Ventilation

In traditionally built leaky houses, fresh air is provided by uncontrolled infiltration from outdoors at rates of one air change per hour or even more, especially during cold weather or when the wind is blowing. A house built with a tight air/vapour barrier may have a natural infiltration rate of only 0.1 air changes per hour (ACH).

Tight houses need mechanical ventilation to maintain adequate indoor air quality by removing airborne moisture generated by cooking and bathing, as well as pollutants emitted from building materials, occupants, and other interior sources. The 1985 National Building Code now requires that all houses have the capability of providing at least 0.5 ACH mechanically throughout the heating season.

Air-to-air heat exchanger



With current technology, heat is recovered from the exhaust air by an air-to-air heat exchanger, sometimes referred to as a heat recovery ventilator or HRV. Annual effectiveness of HRV's in Canada is about 50-70%, depending on flow rate, outside temperature, and the apparatus efficiency. Ventilation heat recovery contributes to the more comfortable draft-free environment of low-energy houses.

An air-to-air heat exchanger, including installation, currently costs in the $1500 range, and even more if the ducting is complicated or if the system is installed after the house has been built. These costs are expected to decrease as heat recovery ventilation becomes established in mainstream residential construction.

Economics

Typical energy savings for a low-energy house are 40-50 GJ per year. The incremental costs to achieve this improved energy performance usually range from a low of $4,000 to a high of 10% of construction costs. A simple way to estimate cost effectiveness is to determine how many years it will take for the annual energy savings to pay back the extra construction costs.
At an average extra cost of $6,500 to save 50 GJ of energy each year, the simple payback for a typical house is about 10 years with energy at $12.75 per GJ (4.6¢ per kilowatt hour). Payback periods are even shorter where energy costs are higher.

Passive solar design features can reduce purchased energy bills even further while simultaneously providing a brighter, more attractive indoor environment. The cost of increasing the solar contribution can be as low as nothing, simply by concentrating the normal window area onto the south side.

ESTIMATED COST FOR UPGRADING REFERENCE HOUSE TO R-2000 STANDARD

Component	Measures	R-2000	Cost
Ceiling insulation	RSI 5.6	RSI 9.0	$ 495
Wall insulation	RSI 3.5	RSI 6.4	$2,876
Basement wall insulation	RSI 2.2	RSI 3.5	$ 82
Basement floor insulation	none	RSI 1.8	$ 341
South windows	double	double	0
Other windows	double	triple	$ 521
Tightness	0.4 ACH	0.05 ACH	$ 639
Heat recovery ventilator	no	yes	$1,460
Total Estimated Cost			**$6,414**

The cost of upgrading the Reference House from **Measures** requirements to R-2000 performance standards using the particular combination

of building envelope improvements given here is estimated to cost $6414, a figure virtually identical to the average incremental cost for R-2000 houses coast to coast.

The most expensive item is the superinsulation; expanding the walls and upgrading insulation in the ceiling, walls, and basement walls, plus insulation under the basement floor. The highest portion of the cost in this example is the walls, which were changed from single stud to double stud to permit the increased insulation thickness. R-2000 monitored data indicates that double-stud walls are cost-effective in areas with more than 5000 degree-days, suggesting that for Ottawa with a 4,700 degree-day climate, double-wall construction may not be the most economic approach.

Beyond R-2000 Performance

Although present low-energy building techniques already permit the construction of even more energy-efficient houses than the R-2000 target, such an approach is usually not cost-effective for the individual homeowner. Once heating costs are down to below $200 per year there is little economic justification for the homeowner to find further energy reductions.

Since all new housing is connected to the electricity grid, many low-energy houses turn to electric heating as it may not be cost-effective to bring in natural gas or fuel oil for such small purchased energy loads. However, there may be an incentive for electric utilities to encourage developments beyond R-2000 requirements if it becomes cost-effective for them to reduce peak electricity demand. Already several utilities in the U.S. offer subsidies to house builders and appliance manufacturers to produce more energy-efficient products, because it reduces the need for expensive new power plants.

3 PASSIVE SOLAR RESEARCH

The most significant initial research work on passive solar technologies was carried out by the National Research Council's Solar Energy Program from 1978-85. During that period, research at NRC's Division of Building Research (since renamed the Institute for Research in Construction) concentrated on monitoring the performance of direct and indirect gain systems in research laboratories and in the field. This research lead to the development of simple calculation guidelines, subsequently incorporated into HOTCAN, a microcomputer program widely used across Canada, particularly in the R-2000 program.

In addition, private-sector research was funded in a number of areas to support the commercialization of early passive solar technologies. This contracted-out work included design studies, performance monitoring, and design tool evaluation.

INITIAL PASSIVE SOLAR RESEARCH

Initial research at the National Research Council focussed on calculating the potential solar gains through windows at various locations across the country and measuring actual performance values to confirm the predictions. When NRC's Solar Program was

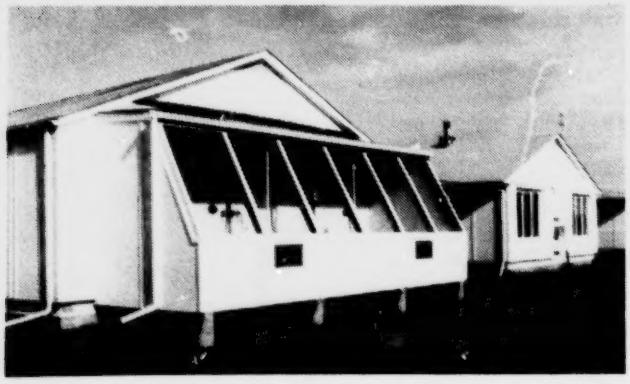
established in 1978, detailed performance monitoring of test buildings was undertaken to compare the performance of the three basic passive systems -- direct gain, indirect gain, and isolated gain.

Passive solar energy is difficult and costly to measure directly, because collection, storage and distribution systems are integrated into the fabric of the building. Several levels of monitoring strategies were developed and a variety of building types have been analyzed to gain an understanding of why different passive systems perform the way they do.

Level A Monitoring

Level A monitoring involves a high degree of experimental control, leading to reproducible measurements and well-documented results. Level A monitored data is intended to validate the design algorithms for computer simulation programs and to provide the basic data for evaluating the accuracy of design predictions.

NRC's Passive Solar Test Facility



The Passive Solar Test Facility at the Institute for Research in Construction in Ottawa consists of three small one-storey buildings, sited side-by-side, that have been used for intensive Level A monitoring of passive solar performance over five winter heating seasons since 1980.

A computer records data at one-minute intervals from each building and integrates the energy values every 15 minutes.

This Canadian facility is one of only a few worldwide capable of sophisticated Level A monitoring and has provided the data for the International Energy Agency to confirm the accuracy of passive solar performance information from its other member countries. Detailed analysis of its data lead to verification of the design algorithms used in computer simulation programs such as HOTCAN and ENERPASS.

Level B Monitoring

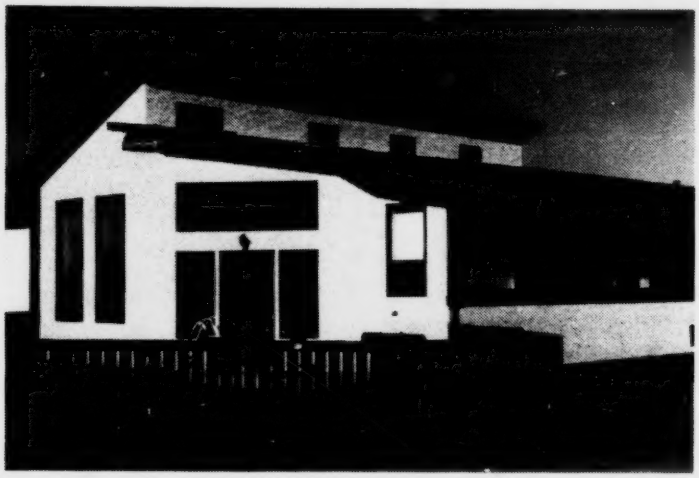
Level B uses a simpler approach called the monthly energy balance to subtractively calculate a building's passive solar contribution. The formula for the calculation is:

Heat Loss - Auxiliary Heat - Internal Gains = Passive Solar Contribution

"Heat Loss" is the calculated total losses from the living areas due to conduction and infiltration, including basement heat loss. "Auxiliary Heat" is the monitored total of all purchased energy required to maintain thermal comfort. "Internal gains" are the heat generated by appliances and lighting (measured) and from the occupants (calculated).

During 1983-1986, over 20 first-generation passive solar/low energy houses were subjected to Level B monitoring through a typical heating season, with a computer recording hourly data on the indoor and outdoor environments and on all purchased energy, plus the thermal performance of the building. Design features included sunspaces, superinsulation and double-stud construction, remote thermal storage, a Trombe wall, unheated buffer spaces, and thermal storage in a variety of building materials.

Passive Solar R-2000 House in Lethbridge



This R-2000 house was Level B monitored for the National Research Council. It has an annual heating load of 58.5 GJ, of which the passive solar contribution was 7.3 GJ, or 12%. Windows are triple glazed.

The 155 m^2 house features 38 x 140 mm framing (2 x 6 in.) plus 38 x 38 mm exterior strapping for a total wall insulation value of RSI 4.9. The attached sunspace has a floor area of 12.4 m^2 with 9.97 m^2 of glazing.

Research Conclusions

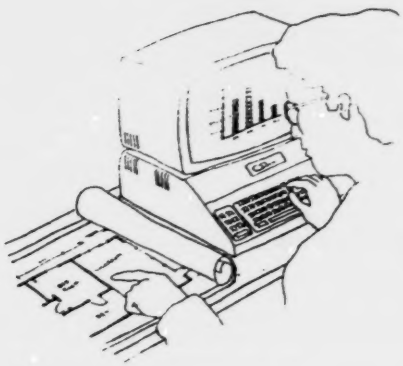
The implication of NRC's research on passive solar design is the understanding that for wood-frame construction in Canada the optimum south-facing window area for lowest energy use is modest.

For best performance, direct-gain passive houses should have no more window area than a normal house, with the only difference being window orientation and quality. South-facing windows have preference, and improved windows (standard triple-glazing or advanced double-glazing with low emissivity coatings) should be installed, particularly on non-south walls.

In cold climates, envelope heat losses dominate, so window areas should be kept small, as required by the building code, and grouped aesthetically on the south. Optimum south glazing area to avoid overheating problems is about 8-10% of the floor area. Large east and west windows should be avoided as they cause overheating outside the heating season and are the most difficult to shade.

Design Tool Evaluation

During 1983-84, NRC funded a two-year survey of more than 400 computer programs that predict passive solar performance. In 1985 a detailed evaluation was performed on eight of the most popular programs, ranging in price from $55 to $1000, using monitored data from NRC's Passive Solar Test Facility.



All the programs were accurate, but varied in user-friendliness and in the number of passive solar design features that could be modelled. The less expensive monthly programs were judged easy and inexpensive to use, but lacking in scope and sensitivity. Most of the packages needed improved sunspace, infiltration and basement modelling. Both HOTCAN and ENERPASS have been upgraded since that evaluation was completed, and both programs can now be used on microcomputers.

A report on the evaluation study is available under the title **Computer Programs for Passive Solar Residential Design.** It is intended to provide guidance to designers on the selection of software for evaluating passive solar and conservation strategies for single-family houses. It discusses the basic calculation methods and then evaluates the eight programs by their scope, ease of use, and cost.

Product Development

The main priority of NRC's Solar Energy Program was to assist the process of product development. The Solar Program scored a number of successes, such as a high-intensity lamp for testing solar collectors to internationally recognized standards, improved solar hot water heating systems, photovoltaic systems for remote radio

beacons and navigation aids, and computer simulation programs for both active and passive solar design.

Other products included a solar light pipe, a device in which light from conventional sources or from the sun travels down a prism light tube with almost total internal reflection. The product can be used in cold-temperature rooms or in explosive atmospheres where conventional lighting is impractical or dangerous. The solar light pipe provides completely natural lighting quality and it offers significant energy conservation and reduced cooling loads in commercial buildings. A major demonstration of the light pipe is now underway in Toronto.

CONTINUING RESEARCH

Early research into more advanced passive solar technologies was underway when the closure of NRC's Division of Energy was announced in November 1984. Responsibility for passive solar research now rests with Energy, Mines and Resources where the Solar Energy Development Program is continuing federal efforts to ensure further progress in passive solar technology.

After consultations with private sector researchers, EMR's Solar Energy Development Program has established priorities in both basic research and in product development. Simplified building monitoring strategies are being developed which will provide useful, practical information for designers, and computer modelling techniques are being refined to provide more accurate information on passive solar performance.

Major emphasis remains on product development, with most research concentrating on superwindows, while other projects are concentrating on phase-change thermal storage materials and an integrated mechanical system. A number of passive solar demonstration projects are also underway.

4 CONVENTIONAL PASSIVE SOLAR SYSTEMS

Although solar energy is free, it is difficult to use cost-effectively because the resource — solar energy — is dilute. In Canada it takes three days of average solar radiation on a one square metre surface to yield the energy equivalent to one litre of oil.

Solar energy is also expensive to use because it is intermittent and the solar energy collecting system must be paid for whether the sun is shining or not. In winter, lower solar intensities and temperatures make it more difficult to collect what reduced solar energy is still available.

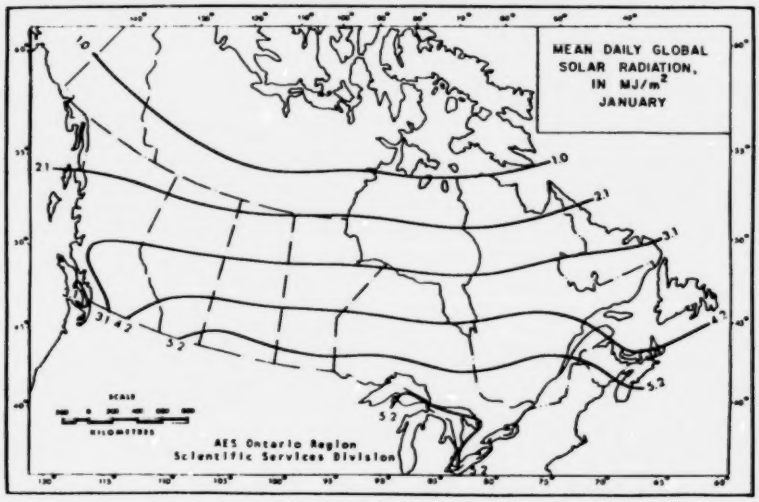
Is there enough solar energy available in Canada to help heat our houses? From an economic point of view, are passive gains large enough to be worth collecting?

SOLAR AVAILABILITY

Energy gains vary across the country, from the higher values of the continental climate on the Prairies to the lower values of the maritime climate on the east and west coasts.

Annual solar energy ranges from 5.2 GJ/m^2 in Lethbridge to 4.6 GJ/m^2 in Toronto to 4.0 GJ/m^2 in St. John's. These values are comparable to those in Europe and the northern United States.

Solar Radiation on a Horizontal Surface



Solar radiation data, like the numbers shown on this map, are usually presented as "global radiation" measurements, meaning that the readings are taken on the horizontal so as to include both direct beam radiation from the sun plus diffuse radiation from the entire sky.

However for solar heating calculations, data is required to determine only the gains through vertical windows.

Global data is particularly invalid for winter heating needs as the sun is lower in the sky and thus more suited to vertical collection, which can also capture radiation reflected from snow cover on the ground.

Solar Gains through Windows

Net heat gain through windows is defined as the difference between the solar energy admitted less the heat lost back to the outdoors. Information on net solar gains can be used during the early stages of building design to assess the potential benefits of passive solar. Net gain values do not include such factors as shading, room reflectance, thermal storage, or overheating. They are based

on net glazing area, with no allowance for frame losses or air leakage.

Monthly values of solar radiation, solar gains, conduction losses and the net heat gain are given for 13 Canadian cities in NRC's **Solar Heat Gains Through Windows in Canada**. Ottawa's figures, given here as an example, are representative of those across the country.

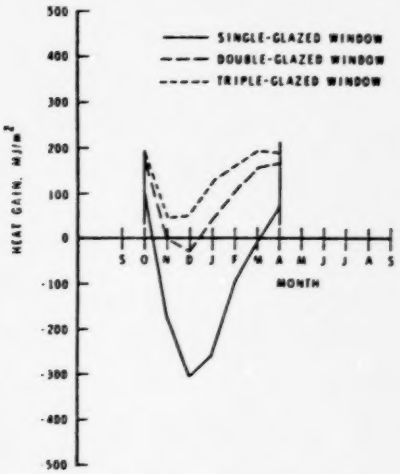
ANNUAL SOLAR HEAT GAINS THROUGH SINGLE, DOUBLE AND TRIPLE GLAZED WINDOWS
Measured data for Ottawa in MJ/m^2

	North	East	S.East	South	S.West	West
Single Glazed						
gross solar gain	711	1271	1798	2060	1756	1221
conduction losses	2486	2486	2486	2486	2486	2486
net solar gain	-1775	-1216	-688	-426	-730	-1265
Double Glazed						
gross solar gain	627	1123	1596	1830	1558	1078
conduction losses	1243	1244	1244	1245	1244	1243
net solar gain	-616	-121	351	585	314	-165
Triple Glazed						
gross solar gain	574	1028	1464	1681	1429	987
conduction losses	820	822	823	823	822	821
net solar gain	-246	206	641	857	607	166

Source: "Solar Heat Gains Through Windows in Canada"

As the table shows, over the heating season single-glazed windows are net energy losers on all orientations. Double-glazed units are net energy gainers for south, southeast and southwest orientations, while triple-glazed units also are net gainers on the east and west, clearly illustrating the advantage of thermally improved windows.

Net Monthly Heat Gains Through South Windows



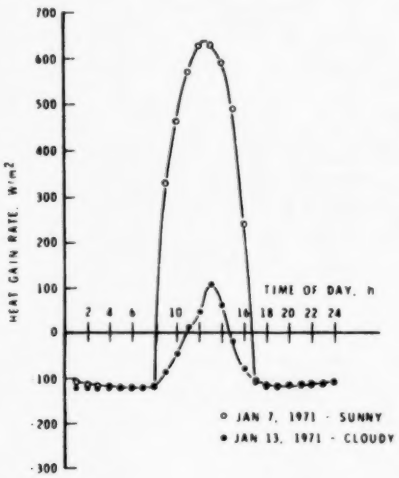
As an example of the variations of net gain during the heating season, this graph shows the monthly total net solar gain for three different types of south-facing window, based on actual weather data for Winnipeg. This pattern is typical for most Canadian locations.

For a south-facing window, a single-glazed window has a net energy gain only in early fall and late spring. A double-glazed window has a net gain except for December and January. A triple-glazed south-facing window has a net energy gain for all months of the heating season.

Windows facing other directions have the same pattern of monthly variation, with a decreasing net gain as they move away from south. For example, a west-facing window only has a net benefit if it is triple-glazed even though the benefit is in spring and fall when the heating requirements of the building are reduced. However during the summer the solar gains are maximum for east and west windows and overheating is harder to prevent with overhangs.

Across Canada each 1 m^2 of south-facing double glazing averages about 0.9 GJ net solar gain during the heating season over a north-facing one, which produces savings of about \$11/m^2 at a typical energy cost of \$12.75/GJ. For an average house with 10-20 m^2 of glazing that could be located on the south rather than the north, the overall solar benefit totals \$110-220 per year.

Daily Net Solar Gains



This example of the daily profile for net solar gain for Winnipeg shows two curves, one for a sunny day and the other for a cloudy day. On the sunny day, the double-glazed window produced a maximum net gain of about 600 W/m^2.

Total daily (24 hour) net gain for sunny Winnipeg winter days averages 7.2 MJ/m^2. On a cloudy winter day the same window loses about 7.2 MJ/m^2

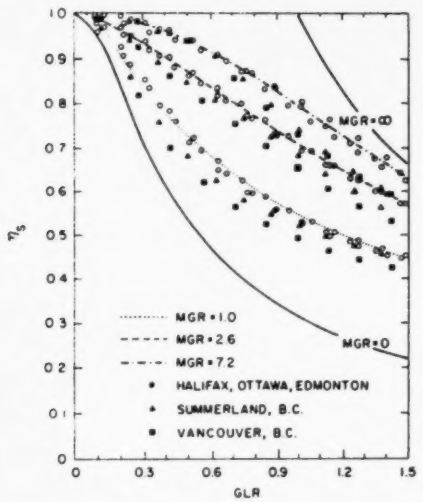
Useful Solar Contribution

In general, the solar gain figures given here do not represent a useful net value against a building's heating load. The useful contribution could be significantly less, depending on such parameters as heating load, thermal storage, glazed area, and allowable temperature swings.

Utilization factors, defined as the fraction of the gross solar gain which contributes to the heating demand, have been calculated for several building types in different locations. For a particular building load and a small glazing area, all the solar gains may be useful if no overheating occurs.

Increasing the glazing area beyond a certain limit will cause overheating and excess solar gains will have to be vented, thus decreasing the utilization factor, whereas increasing effective thermal storage will increase the utilization factor, as the excess gain will be stored for use later on.

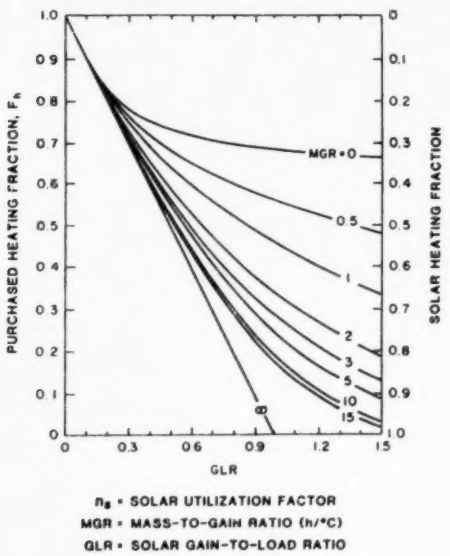
Seasonal Utilization Curves



The solar utilization factors, shown here as a series of curves together with actual data points for five locations, are determined as a function of the building-mass-to-solar-gain ratio, the solar-gain-to-total-load ratio, and the temperature swing the homeowner is will to accept (either 0°, 2.75° or 5.5°C).

The utilization factor curves are widely applicable across Canada, although they overestimate the factor by about 6% for Vancouver where the maritime winter climate has a non-typical distribution of a few sunny days with many cloudy days.

Seasonal Purchased Heating Fraction



The purchased energy portion of the total heating load is shown here as a series of curved lines for different mass-to-gain ratios. The purchased heating fraction is calculated from the total energy heating load minus the useful solar contribution (the net solar gain multiplied by the utilization factor).

DIRECT GAIN SYSTEMS — WINDOWS

Depending on glazing area, thermal mass, and total heat load, the solar contribution to an average house's space heating load can vary from 5-50 GJ. The obvious approach to increasing the contribution is to increase the glazing area by installing more windows.

Unfortunately, overheating becomes a major problem with direct gain systems, aside from the greater expense and increased glare on sunny days. Some people find 2-3°C is the maximum comfortable temperature swing, although most people will accept a range of up to 5°C. Solar gains are generally useless above that amount as they will be vented to the outdoors to prevent overheating. NRC's Level B monitoring confirms this result -- homeowners will draw blinds or open windows to reduce solar gains rather than have the house overheat.

Solar overheating in the summer can be reduced by overhangs and landscaping, such as recommended in **Builders' Guide** and **Conservation of Energy in Housing**.

Generally speaking, two approaches have emerged in the design of direct gain passive solar houses. One approach, nick-named "glass and mass", tries to maximize the solar contribution by using large areas of south-facing glazing and large amounts of thermal mass to prevent overheating. The second approach, nicknamed "light and tight", attempts to maximize energy conservation with light mass, airtight buildings with reduced solar contribution and therefore little need for thermal mass to store solar gains.

Much of the popular literature on solar houses shows huge expanses of south-facing glass, Trombe walls of masonry or adobe, and massive concrete floors. For Canadian conditions, these publications are

misleading. In the southwest U.S. and the Mediterranean, it is practical to use the "mass and glass" approach to attain higher solar fractions. The strong daily temperature variations in warm, dry climates are smoothed out by the large amounts of thermal mass within the building. That approach is also popular because it provides bright open spaces for lots of plants as well as the savings in purchased energy.

Canadian research clearly shows that in our cold climate "light and tight" is the better design strategy; leave the "glass and mass" approach to warmer climates.

With present technology and products, the best design for northern climates is to collect the solar gains available through a reasonable window area and thus avoid overheating problems, and put any additional resources into improved energy conservation. Good Canadian passive design does not add more window area but simply emphasizes south-facing windows, with larger rooms and open areas directly behind them.

Direct Gain Passive Solar House

This two-storey direct-gain house in Prince Edward Island is superinsulated and earth-bermed to the north. The passive solar system consists of 17.7 m^2 of south glazing. Thermal storage is provided by an exposed basement floor concrete slab. The 134 m^2 house has a heating load of 45.5 GJ, 25% of which, 11.4 GJ, was supplied by passive solar.

Window Economics

Window economics are usually based on the net glazing area which does not include mullions, sashes or frames. Window frames represent a significant heat loss. Frames allow no solar gains and usually have an insulation value no better than the glazing units they contain. Depending on window size, the net glazing area typically represents only 75-80% of the total window area.

Can adding window area to the south beyond normal levels be justified from the economic savings? Replacing a wall with an RSI 3.5 (R-20) with a conventional double-glazed window will give an annual net gain of 0.4 GJ/m^2 if all the solar gains are usable, taking into account the thermal bridging effects of the window's sash and frame.

With a generally accepted threshold for cost effectiveness of $120/(GJ/a), about $50/$m^2$ could be justified as the extra expense for the window. However as windows cost about $180-200/$m^2$ compared to a wall costing about $60-70/$m^2$ (plus the exterior finish which for brick can add another $60/$m^2$), the added area cannot be justified with conventional windows, although with advanced windows offering improved thermal performance the economics are expected to change considerably.

Optimum Area for Conventional Windows

NRC Level A monitoring has established an optimum correlation of conventional double-glazed south-facing window to floor area at roughly 10%. Adding more conventional windows simply does not provide a net heating gain during the heating season but does contribute to overheating year-round, particularly if no special

shading features, including landscaping, are included in the design.

The most recent analysis of the performance of a number of house designs, still in progress, indicates that the curves for optimum window area are much flatter than originally thought, probably because the earlier calculations were based on glazing area and ignored frame and edge losses. This conclusion indicates that as more windows are added, the increased solar gains are completely offset by the increased losses, showing once again the need to keep total window area to reasonable levels.

Data on optimum window area is expected to change as the next generation of advanced and superwindows reaches the market, although the importance of good shading design will continue.

Thermal storage

Increasing thermal storage is not an easy solution to overheating. High-mass walls and floors are most effective if they are in full view of the sun during the 9am-3pm collection period. Only the top 15-30 mm thickness (about one inch or so) undergoes any temperature change, indicating that the daytime solar gains are being stored. The same is true of brick or concrete walls — extra thickness is simply not usable. For this reason, thinner materials such as ceramic tile and gypsum wallboard are particularly effective, especially if temperature swings of more than 2° or 3°C are allowable.

High-mass floors may not work as well in practice as they were calculated to do. Whatever their temperature, mass floors feel cold to bare feet, and carpets and furniture reduce their solar exposure and therefore their ability to store thermal gains.

A number of approaches have been tried to augment the solar contribution by transferring the daytime solar gains to isolated thermal mass, such as rock beds, for nighttime use. Although these methods have succeeded in moderating temperature swings, they have not been economic when the value of the energy saved has been compared to the additional cost of the storage.

NRC's Level A monitoring at the Passive Solar Test Facility revealed that increasing thermal mass by a factor of eight resulted in a maximum energy saving of 19%; the research indicates that effective distribution of gains is preferable to simply increasing mass. The research data shows that increasing gypsum board thickness on walls to 50 mm and ceilings to 25 mm reduced purchased energy by up to 17% and decreased overheating from 12% of the time to 10%. By using 100 mm thick bricks for interior walls and 12 mm gypsum board ceilings, purchased energy was reduced by up to 29% and overheating was cut down to less that 1% of the time.

During Level B monitoring, several cost-effective solutions to storage problems were found, including increasing basement window area to allow sunlight on the basement floor slab, increasing the thickness of gypsum wallboard, particularly in the ceiling of rooms with high gains where the large surface area allows for maximum storage. Ducting gains from the ceiling down through mass walls or masonry chimney walls is also effective.

The best solution for thermal storage in conventional passive solar buildings is the use of ordinary building materials, such as gypsum wallboard, interior masonry, and ceramic tile. The search for cost-effective thermal storage systems has found no winners yet, although the new generation of heat pump/heat recovery units that extract heat from the exhaust air and transfer it to the DHW tank offer some potential.

Developer-Built Direct-Gain Solar House

This 205 m^2 low energy house in Kingston, Ontario, has 22 m^2 of south-facing glazing. Annual space heating load ia 88 GJ, of which solar provides 24.5 GJ, or 28%. Extra layers of gypsum board in south-facing rooms and a two-storey interior masonry chimney provide the extra thermal mass. No overheating has been reported.

Mechanical distribution

Auxiliary forced-air heating systems allow solar gains and thermal storage to be distributed throughout the house. One simple strategy is to use a two-speed furnace fan, with the low speed running continuously to distribute gains throughout the house and the high-speed fan cutting in only when the furnace is providing auxiliary heat. More elaborate control strategies have so far been too complicated to work effectively.

INDIRECT GAIN — MASS WALLS

Indirect systems usually rely on a heavy mass wall just inside the windows to provide immediate thermal storage and allow the gains to spread into the house more slowly. This approach is popular

in hot, dry climates where the cool daytime shading they provide to south-facing rooms is a bonus. The mass walls are usually adobe or concrete but sometimes water, often with vents to increase convective heat transfer, and are thick enough to store a typical day's solar gains. Some mass walls have been built in Canada but they have not become popular.

One problem with high-mass walls is the increased costs for materials and construction. After the windows, there is the wall itself plus its foundation and assorted vents, dampers or fans. A final problem is aesthetic. The wall is solid, fine for privacy but it certainly restricts the view.

The major problem with high-mass walls in a cold climate is that the thermal storage is immediately inside the glazing, where heat losses are the highest. Using movable insulation to reduce these has proven to be complicated and labour-intensive.

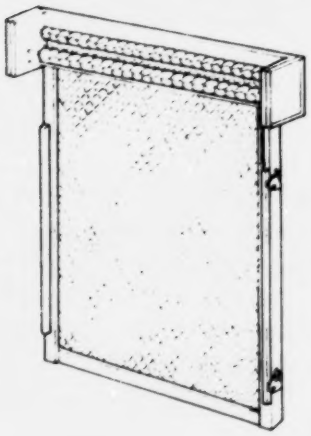
Mass walls can be made to work well in the laboratory, with full-time technicians to manipulate complicated movable insulation and to adjust fans and dampers, but so far no effective movable insulation system has been available. Although research shows that a mass wall approach can out-perform a wall, it can't beat the performance of a window. High-mass walls are simply not cost-effective in our cold climate.

Building codes and aesthetics both require a reasonable window area. To increase that area, at a typical window cost of \$180-200/m^2 plus the added costs of mass wall, sturdy foundations, vents and mechanical systems and then movable insulation, cannot be justified when compared to the cost of the insulated wall that the extra window replaces — about \$60-70/m^2 plus the cost of the exterior finish.

Movable Insulation

Calculations on energy savings with movable insulation look good on paper. Exterior systems either freeze into place when closed or are prevented from closing when ice and snow build up. Interior systems are expensive and labour intensive, and are not effective unless they seal well to reduce convective losses. Glass breakage may occur if the window is subjected to sudden thermal shock.

Thermal Window Blinds



Except for insulated window blinds which raise the insulation value by about RSI 0.35 (R-2) when used, experience with movable insulation has generally been unfavourable. Unless they are opened and closed at the same time that solar gains balance heat losses, movable insulation becomes thermally inefficient. The key to any successful window insulation system is a tight seal and a radiant energy barrier.

ISOLATED GAIN — ATTACHED SUNSPACES

Sunspaces are popular because people are looking for more indoor space with a certain aesthetic quality provided by a bright sunny space, particularly during the winter. Sunspaces are designed to provide a tempered climate suitable for occupancy over a large part of the year. However the vast window areas have an extremely high net energy gain during sunny periods and a high net energy loss for the rest of the time, which make a comfortable climate and an energy efficient design difficult to realize. The twin

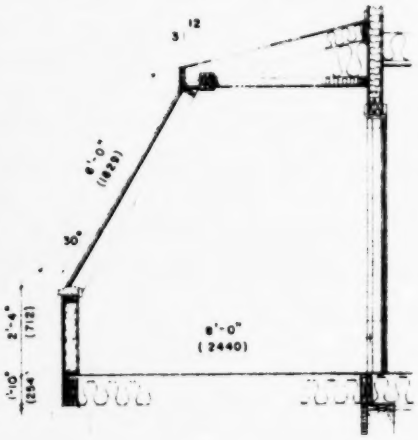
goals of a comfortable living space and energy efficiency can be realized, but only if great care is taken during the design stage and if the homeowner operates the sunspace correctly.

All sunspaces are classed as isolated gain systems, with the overheating problems of direct gain system mply relocated so that excess gains and losses can be isolated from the house.

Although sunspaces have a variety of names, in fact they are used for three basic purposes: as collectors of solar heat for the house, as livable sunrooms, or as horticultural greenhouses. Each type offers different performance characteristics — a fact which has brought grief to many an ambitious owner who built the wrong type for the intended use.

How a sunspace is used has far more influence on energy gains and losses than any design feature. To make a sunspace livable takes a lot of work and energy to control the temperatures. Decide how the space is to be used and then design accordingly.

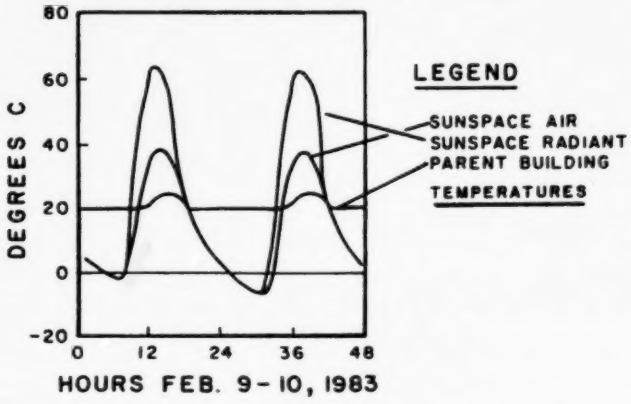
NRC's Attached Sunspace



NRC is still analyzing the monitored results of the attached sunspace at the Passive Solar Test Facility, especially the heat transfer from the sunspace it to the parent building. The information already available, however, is sufficiently compelling for designers to reconsider whether using a livable sunroom as a means of collecting and using solar energy is practical.

If, however, a sunspace is designed mainly for collecting heat and providing a buffer space, it can supply cost-effective energy to the house if it is assembled with cheap components and its construction is airtight.

Monitored Sunspace Temperatures



This figure shows the temperature variations in NRC's low-mass sunspace with 16.3 m^2 net floor area and 9.9 m^2 glazing area. Obviously little use could be made of the sunspace under these severe climatic conditions.

Increased thermal mass within the sunspace helped to moderate the temperature extremes in later experiments, but it limits the quantity of heat available to the house. Good ventilation is also a prerequisite, so that excess gains can be dumped to the outdoors.

The experiment relied on forced convection by fans to transfer heat from the sunspace to the parent building, but this method did not appear to be efficient at moving the large quantities of energy produced. With 38% greater solar gain to the sunspace as compared to the direct-gain system in the neighbouring test unit, the utilized solar gain by the parent building was only 50% of the direct-gain system. However, the sunspace did reduce by 40% the heat lost from the parent building so that its auxiliary heating was only 75% of that required by the direct-gain unit. As with most sunspaces, the heat loss reduction was more important than the solar gains.

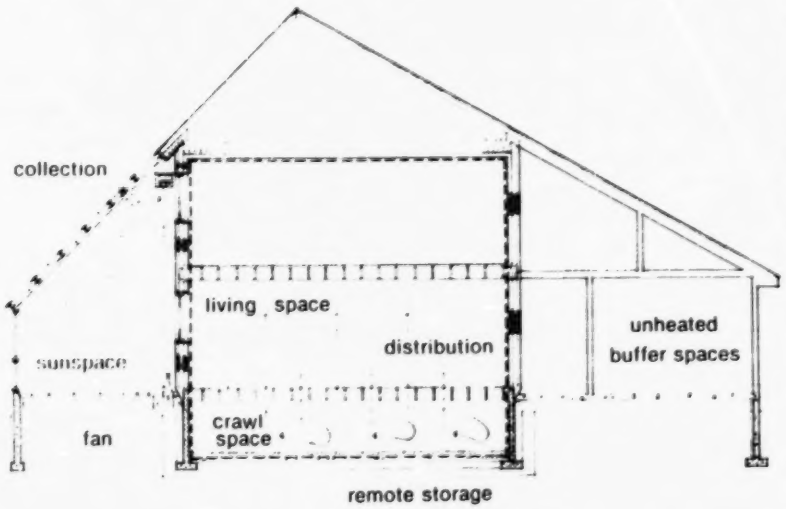
The research also indicates that sloped sunspace-glazings are not the best option in Canada's northern climate. Vertical glazing systems offer better possibilities for control of spring overheating, are less likely to leak or experience dripping due to condensation on the inside of the glazing, and are usually cleaner than sloped glass. Vertical glazing also performs better in winter when it can capture additional solar radiation reflected from the snow.

Sunspaces as solar collectors

A sunspace as a solar collector is designed to maximize the collection of solar energy during the heating season and to transfer it to the parent building. Usually these structures are tall and narrow to concentrate the solar gains at the peak where large fans are required to move enough air to prevent extreme overheating. In one monitored sunspace with 27 m^2 of sloped glazing, temperatures climbed high enough to trip the thermal protection switch on the exhaust fan. The ability to dump excess heat quickly is extremely important.

These units have negligible resistance to heat loss and should never be heated. At night, the space must be isolated to prevent heat loss from the house, and its temperature should be allowed to drop, often below freezing. Temperature swings are extreme.

Solar Collector/Remote Storage Schematic



During the winter the sunspace temperature in this Level B monitored project was maintained with a 3 kW electric baseboard heater set at 10°C. This back-up heating consumed more energy than the entire house, and the heat requirement manifested itself well into the spring.

During the heating season, the attached sunspace/remote storage system provided 43% of the house's 54 GJ space heating load.

To improve their cost-effectiveness, these solar collecting sunspaces should be built as tight as possible, with light-weight, inexpensive materials. Single glazing is optimum.

As with all sunspaces, this type of structure helps to reduce heat loss from the house by providing a thermal buffer to the outdoors, particularly if the common wall is highly glazed. As with most sunspaces, the energy savings through reduction of parent building losses are usually greater than solar heat gains.

Sunspaces as Sunrooms

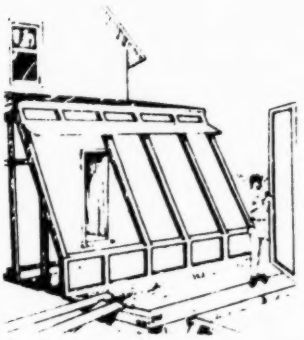
A sunroom is designed as a habitable space for year-round use, especially bright and pleasant during the winter. Sunrooms work best if they are closed off at night and during cloudy weather; if auxiliary heat is used they become a thermal liability. Sunrooms are net energy losers if they are used improperly.

Thermal improvement requires less glazing, tighter construction, and more insulated area. During periods of solar gain, heat can be transferred into the house by passive convection or with small electric fans. Thermal storage is best used to temper extreme temperatures and to provide some but not all the heat for overnight. Thermal storage beyond one night is simply not practical. Storage should be integrated into the structure and the finish materials. All mass should be fully exposed to the sunlight and distributed throughout the space.

Sunrooms are less likely to overheat during the summer if sloped glazing is avoided and if adequate ventilation is provided.

Sunspaces as Greenhouses

A greenhouse is designed to optimize plant growth over an extended growing season. Auxiliary heat and light are required when insufficient solar energy is available for good plant growth, especially when days are short and nights are long. For these reasons, a greenhouse should be kept small and not used during the coldest months.



Although excess solar heat can be transferred to the house, some designers recommend not doing this to avoid humidity, odour, and insect problems in the house. In this case, thermal storage can be provided in the greenhouse by blowing the heated air below growing beds or even under the ground.

With greenhouses, high humidity levels, frequent watering, and condensation and drainage problems become major construction issues. Constant attention is required to prevent any overheating from damaging the plants.

Horticultural sunspaces are frequently glazed with relatively inexpensive commercial greenhouse UV-resistant polyethylene films to reduce costs. The low-energy strategy is to reduce glazing areas to reduce night-time energy losses, to provide insulating shutters or curtains, and to use artificial lights to provide for plant growth.

Conclusions

The overall conclusion is that with present technology only modest passive solar contributions from sunspaces are possible when economic energy efficiency is sought. If sunspaces are heated they become net energy losers because of their large window area and low insulation levels.

Sunspaces should always be isolated from the house to reduce heat losses when the sunspace cools off at night. As temperatures drop, condensation will occur on the interior surface of the glass and gutters should be provided.

Only the glazed area necessary to produce the desired lighting levels should be used. To avoid overheating in summer and to reduce costs, the windows are best left vertical and oriented to the south.

A retrofit of a sunspace onto a patio door makes good sense as it limits heat loss from the door. Also, glazing between the solarium and the house gives light and solar energy to the house with lesser losses than if the glazing were exposed directly to the outdoors.

5 ADVANCED PASSIVE SOLAR/LOW ENERGY BUILDING APPLICATIONS

Advanced passive solar building applications are now in the research and development stage and several new products are already on the market. Advanced passive systems are technically more sophisticated and require improved components such as enhanced windows and heat pump/heat recovery devices with the ability to capture excess solar gains and to provide thermal storage.

With these advanced technologies it may be possible to meet the R-2000 performance standard with less cost than with conventional products, although the service life of the new mechanical systems is still unknown. The most likely combination of features for passive solar/low energy building in the future, based on current research, is a house with superwindows, insulated to "Measures" requirements, and a heat-pump/heat recovery system with thermal storage.

Because advanced mechanical systems may not need the same high levels of airtightness and superinsulation, their biggest advantage is expected to be that they can also be used on existing buildings, unlike present techniques which are generally limited to new construction or radical retrofits.

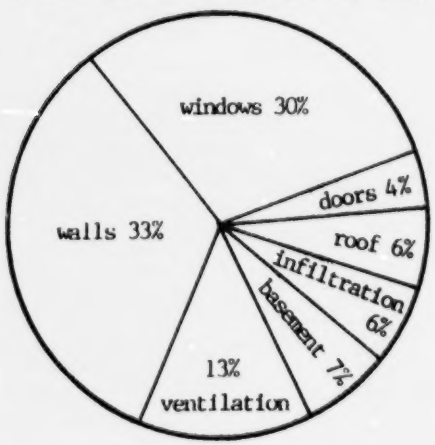
PROBABLE FEATURES OF ADVANCED PASSIVE SOLAR HOUSES

* Insulation levels as specified in **Measures**
* Advanced or superwindows
* Heat pump/heat recovery with thermal storage

SUPERWINDOWS

The key to enhanced passive solar performance in northern climates is windows that transmit more solar energy and that provide better thermal resistance. A sheet of regular glass transmits about 77 percent of solar energy, whereas a sheet of low-iron glass transmits about 90 percent. Low-iron glazing is now standard in solar collectors, but is not common in windows. Research into superwindows is concentrating on improving thermal performance.

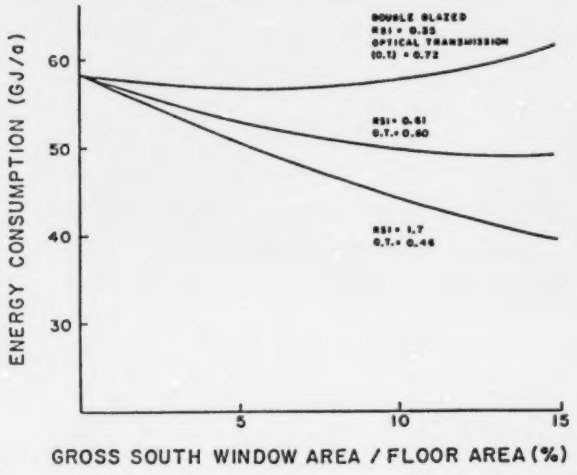
Heat Loss by Building Component
Reference House Built to R-2000



With the Reference House upgraded to R-2000 standards, heat loss through conventional double-glazed windows amounts to 30% of the total heating load. Superwindows are expected to reduce this loss significantly while offering increased comfort, higher humidities, warmer glass temperatures, and reduced condensation.

The superwindow research program has established the goal of an RSI 1.0 (R-6) window to encourage new concepts rather than the improvement of conventional technology. Products that are expected to be commercialized within the next few years are improved triple windows of RSI 1.06 (R-6) and super quadruple-glazed windows of RSI 1.7 (R-10).

Effect of South Window Thermal Resistance on Building Heating Load



In combination with improved mechanical systems, superwindows will allow larger window areas and increased solar contributions to the heating load. As this chart shows, optimum area for conventional windows is only 6-7 percent, whereas for advanced and superwindows increasing the window area beyond that amount will provide increasing net solar gains.

For advanced windows with a thermal resistance of RSI 0.6 (R-3.4), the optimum area is between 10-15 percent. Superwindows with RSI 1.7 (R-10) appear to have no optimum size from an energy contribution viewpoint.

Improvements in window technology fall into two categories--improvements to the glazing components and improvements to edge spacers and frames.

Low-Emissivity Coatings

Low-emissivity coatings are the first step in improving window performance because they reduce radiant heat losses, which represent almost half the energy lost through windows. These ultra-thin

coatings are transparent to short-wave solar radiation but reflect long-wave heat radiation. Cost and durability are the two major issues for low-E coatings, so improvements in both areas continue to be areas of research. Low-E coated glass is rapidly becoming popular, with industry spokesmen claiming that it will have 25 percent of the market within five years.

Low-E coatings can be applied to either glass or thin-film plastics. Two different techniques are used to put low-emissivity coatings on glass: sputtering which produces a relatively soft coat, and spraying which produces a harder coat. Sputtering requires a complex manufacturing process within a vacuum chamber. Because the sputtered coating is extremely thin and not durable, it can only be used on the inner surface of sealed units. Sputtered coatings with an emissivity of 0.1, which block all but 10% of the radiated heat loss, are already manufactured in Canada.

Sprayed pyrolitic coatings produce a harder, more durable layer and are applied during manufacturing while the glass is still hot. Usually these coatings have an emissivity of 0.45, although current research has produced improvements in the laboratory. The major advantage of these sprayed coatings is their lower cost since a vacuum is not required during the application process. Because the hard coating does not need to be protected inside a sealed unit, hard-coated low-E glass can be used as a separate storm window or to triple-glaze an existing window.

Low-E coatings on thin polyester films, such as "Heat Mirror", are already in use for advanced windows. Because these coatings are soft, they have to be protected by installing the film inside a double glass unit, thus offering a further advantage of triple glazing but with less weight than three layers of glass. Research

is continuing on hard coatings for thin-film plastics, but so far no products are commercially available.

Gas Fill

A second approach to improving the thermal performance of glazing is to reduce conductive and convective losses. Inert non-conductive, convection-suppressing gases such as argon can be used to fill the cavity between panes in a multi-glazed window. The effectiveness of the gas is improved when used in combination with low-E coatings. Windows with low-E glass and argon fill are already on the market, offering a thermal insulation value of RSI 0.6 (R-3.4)

Multi-glazings

Another way to reduce convective losses is to use multi-glazings. Unfortunately pressure equalization becomes a major problem as windows become thicker. As the temperature of the window and the surrounding atmospheric pressure changes, the pressure of the fixed volume of gas between the panes also changes. With conventional double-glazed units, the seal is usually able to accommodate these pressure changes for 10-15 years, but as the number of glazings and thus the overall volume increases, the pressures become larger, often resulting in glass breakage and seal failures. One of the major research areas in superwindows is to find an economic solution to pressure equalization in multi-glazed windows.

Frames and Edge Spacers

The present cost for sealed double-glazing units represents only 15-20 percent of the cost of a conventional window. With the huge

expenditure on sash and frame, it appears prudent to improve the thermal performance of these components, and research is underway in this field. So far, work on window frames has concentrated on low-conductivity, foam-filled plastics which drastically reduce thermal losses.

A significant portion of the heat loss through conventional windows is conducted through the metallic spacer at the edges which separates the two panes. An insulated spacer could reduce frame and edge losses by an estimated 30%, and already several new plastic spacers are being marketed.

THERMAL PERFORMANCE OF DIFFERENT TYPES OF WINDOWS

Window Type	Insulation Value (including frame)
Conventional double glazed	RSI 0.35 (R-2)
Conventional triple glazed	RSI 0.5 (R-3)
Best currently available: triple-glazed double glass plus low-E plastic film with conventional spacers and frame	RSI 0.7 (R-4)
Under development	
Improved double glazed low-iron glass with low-E coating argon gas, insulated spacer and frame	RSI 0.7 (R-4)
Improved triple glazed low-iron glass and low-E plastic film argon gas, insulated spacer and frame	RSI 1.06 (R-6)
Super quadruple two outside low-iron glass two low-E coated inner plastic films argon gas, insulated spacer and frame	RSI 1.76 (R-10)

ADVANCED HEATING SYSTEMS

Several strategies for advanced house heating systems are being explored. The main improvements in integrated mechanical systems are occurring in heat-pump technology. Indoor heat pumps allow for more efficient use of energy, since several heating and cooling requirements can be served by a single system.

Ventilation heat-pump heat-recovery systems, more popular in Scandinavia than air-to-air heat exchangers, are now available on the Canadian market. These systems use a heat pump to upgrade heat from the exhaust air and return it to the house or transfer it to the domestic hot water when no space heating is needed. The big advantage of these systems is that they can be used year-round-- heating in the winter, cooling in the summer, and preheating the hot water supply year-round. Present costs are high, although prices are expected to drop as the technology advances and larger production runs allow economies of scale.

Integrated mechanical systems

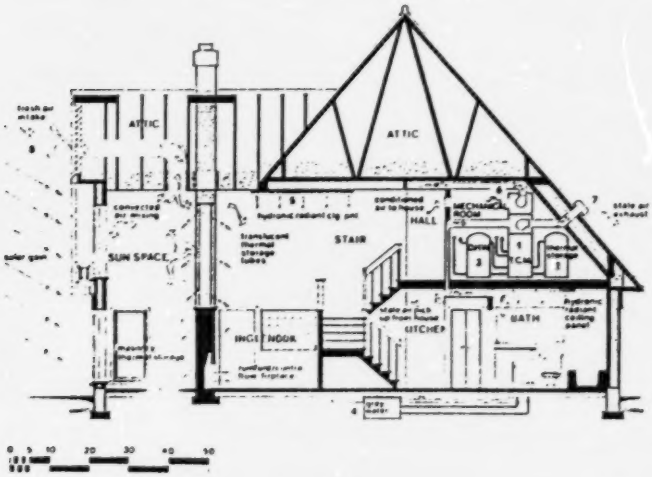
Research is being conducted into combining ventilating, heating, cooling, heat recovery, and even refrigeration into one mechanical system that can also provide thermal storage for increased passive solar gains.

One design, still in the research stage, uses the phase change from ice to water to store excess solar gains, which the heat pump then refreezes when heat is needed. The storage tank runs around 0°C using the enhanced storage available from the phase change between water and ice. Excess gains are stored by melting ice and space heat is added by freezing water. The system extracts energy from

the waste air and waste water and balances the solar and internal gains against the house load.

An engineering prototype is being assembled and a full-sized advanced passive solar demonstration house using the system is being planned.

Cross-Section of Advanced Passive Solar House



[1] control module
[2] low-temperature thermal storage tank
[3] conventional DHW system
[4] grey-water heat exchanger
[5] hydronic radiant ceiling panels
[6] heat pump/air handling unit
[7] exhaust
[8] ventilation intake

The house is expected to feature superwindows, a gasketted foil-backed drywall air barrier, low energy lighting and appliances, but no basement. Radiant heating will allow lower indoor air temperatures. A sunspace will preheat ventilation air. Excess solar gains are expected to supply 40% of the DHW energy load.

Other approaches being examined include adding heating and cooling capabilities to air-to-air heat exchangers. Integrated space heating and hot water heating systems are already on the market.

Radiant heating

A combination of passive solar architecture, superinsulation, airtightness, and high thermal mass with its slow temperature

response can make radiant heating an attractive option for energy-efficient buildings. Although radiant heating is not a new technology, it is receiving some attention as part of the search toward building better passive/low energy houses.

When auxiliary heating demand is low, internal gains from appliances and occupants can be supplemented by ceiling-mounted infrared panels or light fixtures with individual room control. Because radiant heat is used only where it is desired by the occupants, the building can be maintained at lower temperatures, increasing overall thermal efficiency by reducing the rate of heat loss. Care is required in locating ceiling radiant heating panels to avoid discomfort to people standing below.

Ventilation preheat

Several options are being examined for preheating incoming ventilation air — through a sunspace, a preheat window, or even through the basement where the cooler infiltration air will be less noticed.

Preheat windows use the outer spacing of a triple-glazed window as an in-coming duct for ventilation air. In theory all the heat loss through the inner two glazings can be recaptured by the incoming air, thus producing a glazing unit with almost no heat loss at all. Such a window could work well with an exhaust-air heat pump which would provide negative pressure to draw air in through the window.

Studies are under way to determine optimum spacings and air flows, and prototypes are being developed to resolve installation and mechanical system hook-up problems. Cost-effectiveness of these systems remain the key issue.

Two methods of using the heat generated in a sunspace are receiving further research. Preheating ventilation air by drawing it in through the sunspace is one approach, based on the principle that even at night a sunspace is warmer than the outdoors. The other approach uses a heat pump to preheat the domestic water by using solar gains from the sunspace.

Active Solar Heating

Using active solar collectors for space heating is not practical in Canada, except in special cases such as warehouses or crop drying where no thermal storage is required. The obvious problem is the bad mismatch between solar availability and heating demand. The high capital cost of an large active solar system used only during the winter remain the major obstacle.

THERMAL STORAGE

At present there are no products specifically for increasing thermal storage capacities, except for heat-pump/heat-recovery systems which allow some thermal storage by transferring excess solar gains to the DHW system.

Several research projects are examining phase-change materials, particularly for increasing the storage capacity of gypsum wallboard. If this research is successful, a new type of thermal storage wallboard may be on the market within the next few years.

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Montreal Road
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Renewable Energy Branch
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OTHER INFORMATION SOURCES

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For more information of active solar products, including system warranties and installer certification, contact:

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For more information on government grants for solar DHW systems, contact:

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